CHAPTER VI

Epidemiological Considerations

ALTHOUGH this study was designed primarily to evaluate the effect of ultraviolet irradiation on the incidence of postoperative wound infection, there was also an opportunity to accumulate and analyze data relative to the epidemiology of such infections. This chapter reviews factors that may influence the development of infection, and methods of transmission, as they are related to the development of postoperative infection.

It is common knowledge that surgical services have the highest hospital-associated infection rates of all hospital services (Farrer and MacLeod, 1960; Minchew and Cluff, 1961; Williams, Blowers, Garrod, and Shooter, 1960; Brachman, 1963). Patients undergoing operation face special risks that increase their opportunity to develop hospital-associated infections. Particularly important are the factors directly related to operation, such as tissue trauma, necrosis, compromised blood supply, use of drains, and prolonged procedures. In addition, inhalation anesthesia increases the risk of respiratory infection, the use of intravenous fluids increases the risk of septicemia or local infection, and the longer period of hospitalization for the average surgical patient increases the risk of developing hospital-associated infections.

Many of the reported studies of surgical wound infection have been retrospective, or have concerned data from a single institution and compared them with data from other institutions with dissimilar characteristics, such as populations or definitions. The present study was unique in that it involved the prospective, simultaneous collection of data from five institutions over a consecutive 27-month period in accordance with similar definitions and methods of surveillance. The development of a standard, comprehensive definition of wound infection (Chapter III) led to the use of objective criteria in determining whether a specific wound was infected. Subjective attitudes cannot, however, be totally removed, which was recognized in allowing individual investigators to evaluate the importance of, for example, a stitch abscess.

The presence of bacteria in the postoperative wound was clearly shown not to be a criterion of clinical infection. Wounds may become contaminated by bacteria and even support the multiplication of bacteria without showing evidence of bacterial sepsis, just as the nares of a nasal carrier can be contaminated without clinical illness. The important considerations were whether the patient's recovery was in any way compromised by the presence of bacteria in the wound, and whether bacteria were disseminated from the wound and associated with the subsequent development of secondary infection. Also of importance to this study was the 28-day follow-up which allowed late-developing infections, especially those that developed after discharge from the hospital, to be included in the analyses. Barnes *et al.* have reported (1959) that 20 per cent of their cases of postoperative sepsis were discovered after the patient left the hospital.

The over-all incidence of postoperative wound infections reported in this study (7.4%) compares favorably with reports from other institutions (Farrer and MacLeod, 1960; Ford and May, 1962; Meleney, 1935; Howe, 1954; Burnett *et al.*, 1958; Clarke, 1957b; Douglas, 1963). Within the United States, however, lower rates have been reported. Dineen has reported (1961) an infection rate of only 0.87 per cent in 11,426 patients. Minchew and Cluff reported (1961) an over-all postoperative staphylococcal infection rate of 1.3 per cent.

Similar variation has been noted in other countries. The British Public Health Laboratory Service, summarizing 3,276 operations in 21 hospitals, reported (1960) a sepsis rate of 9.7 per cent, with a range among these hospitals of from 4.7 to 21.8 per cent. Williams *et al.* reported (1959) an incidence of 4.7 per cent on a general surgical service. Moore and Gardner reported (1963) studies involving 559 surgical patients and a postoperative sepsis rate of 12.7 per cent, with 9.1 per cent showing definite suppuration. McNeill *et al.* found (1961) a rate of 22 per cent in 240 males on a general surgical ward. Jeffrey and Sklaroff, reporting (1958) from the Edinburgh Royal Infirmary, noted an incidence of serious infections among 673 clean wounds of 9.8 per cent, with an additional incidence of 16.3 per cent of trivial infections.

Loewenthal reported (1962) that 8 per cent of a series of clean wounds in Australia showed evidence of infection. Markham and Shott, reporting (1961) from New Zealand, stated that 4.6 per cent of 4,095 surgical admissions developed postoperative wound infections.

In Canada, a study of 55,068 surgical admissions to 45 hospitals revealed a postoperative staphylococcal wound infection rate of 1.4 per cent (National Research Council Associate Committee on Control of Hospital Infections, 1960). Hnatko *et al.* reporting (1963) from a Canadian hospital that performed between 4,000 and 4,600 operations per year from 1959 through 1961, found postoperative infection rates of 2.02, 1.20, and 1.14 per cent, respectively, for the three years.

The extent of the variations in postoperative wound infection rates among the five institutions participating in the present study (the highest was almost four times the lowest), despite uniformity in definition of wound infection and in methods of surveillance, suggests the influence of local factors; similar variations have been noted in other multihospital studies (National Research Council Associate Committe on Control of Hospital Infections, 1960; Public Health Laboratory Service, 1960). Most of the single factors thought to influence the likelihood of wound infection affected the wound infection rate in the same direction (i.e., increased or decreased it) among all five institutions, but not necessarily to the same degree.

Effect of Type of Operative Procedure

When considering postoperative infection rates for any institution, it is important not to be misled by an over-all low rate. Detailed analysis of infection rates for specific types of operation is necessary in order to pinpoint the problem areas that may be associated with significant infection rates, even if the over-all rate is considered insignificant. For example, in the current study (with an over-all infection rate of 7.4%), colostomy with exteriorization of the cecum was associated with the greatest risk of infection, 19.3 per cent (Table 19). Of the clean operations, radical mastectomy had the highest infection rate, 18.9 per cent. Amputation at the thigh (17.8%), nephrectomy (17.3%), and choledochostomy (17.1%) had the next highest infection rates.

In Minchew and Cluff's report (1961) on postoperative staphylococcal wound infections, the highest attack rates were shown to follow radical neck dissection (11.1%) and amputations (10.0%). Mastectomy (not divided into radical or simple) was associated with the eighth highest rate (5.0%). Hnatko *et al.* (1963) found that the highest postoperative infection rate was associated with gastrectomy (8.9%), and the next highest with nephrectomy (7.7%), cholecystectomy and explorations (4.0%), laparotomy (3.8%), and radical and simple mastectomy (2.4%). The Public Health Laboratory Service reported (1960) that, in 21 hospitals in England and Wales, the highest infection rates in clean operations were associated with

cholecystectomy (21.0%) and breast operations (15%).

Thus, there are major differences among the several studies as concerns the operations associated with the highest infection rates. Considering the five hospitals in our study separately, the individual variation in infection rate by type of operation (Table 19) lends weight to the belief that multiple individual factors in each institution influence the development of postoperative wound infections.

Effect of Ultraviolet Irradiation

Ultraviolet irradiation is clearly bactericidal (Chapter IV), but the failure of a reduction in airborne bacteria to hinder the development of postoperative wound infections indicates the presence of pathways for infection other than air. The system of wound classification (refined-clean, other clean, clean-contaminated, contaminated, and dirty) represented an attempt to extract as many variables as possible from the evaluations in order to delineate the effects of individual factors more clearly. In four of the five institutions, the postoperative infection rate increased stepwise from the least to the most contaminated wounds, which suggests endogenous contamination. For the five taken together, the refined-clean wounds accounted for 43 per cent of all operations, but only 19 per cent of all wound infections, whereas the nonclean operations (clean-contaminated, contaminated, and dirty) accounted for 25 per cent of the operations, but 48 per cent of the infections. Ultraviolet irradiation of the operating room significantly reduced the incidence of postoperative infection associated with refined-clean wounds, but not the incidence associated with others; in fact, in contaminated and dirty wounds, the observed incidence of infection was higher after irradiation.

Various explanations may be considered to explain the latter phenomenon; that is, there was a reduction in the number of resident bacteria in irradiated wounds, which made it easier for bacteria from other endogenous or exogenous sources to localize and multiply, which led to infection (the bacteriologic data from wound washings at the time of operation indicated a decrease in the number of bacteria found in irradiated wounds); or irradiation affected tissues adversely, and created an environment favorable to the growth of bacteria from any source whatever; or random variation could account for the observed differences, particularly in view of the fact that the experience was different from one institution to another.

Effect of Age of Patient

Apart from other influences, age is of major importance in the development of postoperative wound infections. The lowest infection rate (4.7%) was seen in the 15- to 24-year-olds, and those that followed increased steadily with age. Infants also had a higher infection rate, possibly reflecting the immaturity of their resistance mechanisms. These trends were apparent even when adjustments were made for age differences in the distribution of classification of operation. Markham and Shott showed (1961) in a study of 364 hospital patients that the older patients (i.e., above 50) had a higher incidence of septic lesions than expected and believed that "age alone may operate as a predisposing cause." Minchew and Cluff found (1961) in their study of postoperative wound infections that the age-specific attack rate rose steadily from 0.4 per cent for persons under 10 to 5.1 per cent for those of 70 to 79. The Public Health Laboratory Service report (1960) from England and Wales also shows an increase in infection rates with advancing age. Barnes *et al.*, however, found (1959) no predictable relationship between age and infection rate in wounds following inguinal herniorrhaphies and abdominal hysterectomies.

Effect of Sex and Race of Patient

When infection rates were adjusted for wound classification, neither sex appeared to have a higher rate. The slight difference by race was so small as to be unimportant when compared with other influencing factors. Other studies have also shown no significant variation with sex or race (Minchew and Cluff, 1961; Public Health Laboratory Service, 1960).

Effect of Metabolic and Nutritional Conditions: Diabetes, Obesity, Malnutrition, and Steroid Treatment

Infection rates were significantly higher for patients with diabetes mellitus, obesity, or malnutrition, or those on steroid therapy. The increased rate in diabetic patients appears to be directly related to the large number of elderly patients in this group. Dineen (1961) found diabetes mellitus to be the most frequent complicating systemic disease, present in nine of the 100 patients in his study. Obesity itself appears to be the factor related to the excessive infection rate in obese patients. The impaired resistance and delayed healing of adipose tissue are commonly recognized. The higher infection rate among malnourished patients seemed largely explained by their atypical distribution among the five hospitals. The higher infection rate among the steroid-treated patients was probably related to their longer operative procedures, and perhaps to other factors as well. However, the known effect of steroids in reducing resistance to infection cannot be dismissed.

Effect of Remote Infection

Patients with "remote" infections had a significantly higher wound infection rate for reasons not apparent from this study. The nasal carriage status of patients before operation was not studied.

Effect of Method of Wound Closure and Drainage

Whether differences in the method of skin closure affected the infection rate is not clear. Higher infection rates were associated with drains, regardless of wound classification. This has also been reported in other studies (Public Health Laboratory Service, 1960; Douglas, 1963).

Effect of Duration of Operation

The length of the operation was a major factor in the development of postoperative wound infections, with the longer operations being associated with a higher infection rate. This has also been reported in the study by the British Public Health Laboratory Service (1960). This finding was independent of wound classification. There were no significant differences in rates of postoperative infection between the irradiated and the unirradiated wounds when classified according to length of operation, which is further evidence of the lack of specific ultraviolet benefit in preventing postoperative wound infections. Dineen (1961) and Minchew and Cluff (1961) did not find any association between infection and duration of operation. Further studies are needed to determine the relative influence on the development of infection as concerns the amount of tissue exposed to ultraviolet irradiation, the number of bacteria that can gain entrance to a wound during a prolonged operation, the increased trauma to tissue, and other factors that may be associated with a prolonged operation.

Effect of Urgency of Operation

It would be expected that the more urgent the operation, the greater the likelihood of infection, in that the patient might be physically less well prepared for operation. Indeed, the urgent and emergency operations were associated with higher infection rates, but when those rates were adjusted for wound classification, there were no significant differences from elective operations. This indicates that a higher proportion of nonclean than clean operations were "urgent" or "emergency" operations. Dineen (1961) reported a wound in-

fection rate three times as high for emergency procedures (2 to 4%) as the over-all rate (0.87%). He did not mention adjustment of these rates for type of operation.

Effect of Date of Operation

The over-all postoperative wound infection rate did not show a seasonal variation, either for the five institutions taken together or for individual institutions. Nor did Barnes *et al.* (1959) or Howe (1956) observe a seasonal variation, but some reports have indicated a definite seasonal trend in postoperative infection rates (Dineen and Pearce, 1958; Thornton and Cluff, 1963). The operating-room bacterial fallout pattern did, however, vary seasonally in two institutions in the present study. In Hospitals 1 and 4, the numbers of airborne bacteria increased during the middle months of the year, with peaks in late summer or early fall and lows in winter (Fig. 36). No seasonal variation in the recovery of bacteria from nasal swabs was noted among personnel cultures obtained in this study.

Analysis of the data by quarter year for individual species of bacteria recovered from the air and from wounds reveals widely divergent patterns (Fig. 37), which supports the belief that airborne bacteria were not the primary determinant of wound infection. This belief is also supported by the peaking of recovery of airborne bacteria from two institutions from August through October without concurrent peaks in the incidence of wound infection in those institutions (Fig. 22, 25, 36).

Effect of Time of Day of Operation

It has been reported (Williams, Blowers, Garrod, and Shooter, 1960; Douglas, 1963) that the infection rate increases with the time of day. This has been associated with the environmental contamination in a given operating room, which has been shown to increase as the day progresses and more operations are performed. Douglas reported that the infection rate associated with first operations (in a given day) was 0.4 per cent; with second operations, 1.8 per cent; third, 2.2 per cent; fourth, 7.9 per cent; and fifth, 6.7 per cent. (These data were adjusted for duration of operation, length of incision, use of drains, and age of patients.) This general trend has also been linked with increasing fatigue of the surgical team and the presence of unknown factors. However, Bernard and Cole (1962) found no difference in airborne bacterial counts between morning and afternoon samples (their data were not broken down by hour).

In the present study, the bacterial fallout pattern for all operating rooms taken together shows a rise to a peak value at 10:00 to 11:00 a.m., followed by a gradual decline (Fig. 35). The raw data concerning the postoperative wound infection rate calculated by time of operation also show an increased rate of infection with time, but when the data are adjusted for urgency and wound classification, the increase disappears, presumably because *elective* operations are generally *scheduled* for the earlier hours.

Effect of Duration of Preoperative Hospitalization

Greater length of preoperative hospitalization was associated with an increase in infection rate apparently unrelated to specific, previously mentioned patient factors: from 6.0 per cent (0 to 1 day of preoperative hospitalization) to 14.7 per cent (over 21 days). This may be related to the greater virulence of organisms circulating in the hospital and subsequently colonizing the patient than of those brought in by the patients.

Effect of Administration of Prophylactic Antibiotics

Prophylactic antibiotics were administered to 30.7 per cent of the patients in the study, with individual hospital variation from 15.1 to 37.6 per cent. Combinations of

penicillin and streptomycin were most commonly used. As expected, wounds considered more likely to become infected were more likely to be treated prophylactically with antibiotics. When the data were adjusted for wound classification, the infection rate for patients who received prophylactic antibiotics was 12.2 per cent, and for those who did not, 5.2 per cent, a statistically significant difference. There was, however, the impression that antibiotics were not always used prophylactically, but at times specifically for the treatment of suspected infections. There are other reports that indicate the higher rates of postoperative wound infection when antibiotics are used (Minchew and Cluff, 1961; Barnes *et al.*, 1959; Sanchez-Ubeda *et al.*, 1958; Howe, 1956; Tachdjian and Compere, 1957).

Dineen found (1961) a higher infection rate in his patients who received prophylactic antibiotics preoperatively than in those who did not. In connection with previous experimental work (1960) he stated that "there was a decrease in host resistance when the bowel flora was reduced or markedly altered. This was presumed to be on the basis of nonspecific resistance and not associated with actual immune reactions." He also stated that preoperative antibiotics remove or destroy the "susceptible organisms and thus permit the colonization of the nasopharynx, wound, lung, or gastrointestinal tract with resistant, more virulent organisms." However, until an adequately randomized control study of the effects of prophylactic antibiotics is conducted, the effect of this procedure on the incidence of postoperative wound infection will remain unknown.

Studies of Bacteria Carried by Operating-Room Personnel

The bacteriologic studies performed were not all-encompassing, but did allow the evaluation of three specific areas of concern as regards the development of postoperative wound infection: 1) nasal cultures from the personnel helped define the role of the personnel nasal carrier in wound infection; 2) the use of sedimentation plates in the operating rooms made it possible to evaluate the effect of ultraviolet irradiation on the airborne bacteria that settle out during operation; and 3) the identification of the bacteria present in the postoperative wound and in the drainage from a postoperative wound infection made it possible to correlate the presence of specific bacteria and infection. The degree to which these cultures were obtained among the five institutions varied, but the technics of culture and identification were similar (Appendix C).

The over-all prevalence of coagulase-positive staphylococci cultured from the nares of operating-room personnel was 20.7 per cent (compared with a range of from 20 to 70% reported in other surveys, e.g., Nahmias and Eickhoff, 1961). The variation from institution to institution (ranging from 13.4 to 31.0%) attests to the existence of variables in operation at each institution. The variability in the percentage of personnel carrying coagulase-positive staphylococci at any one time, from 14 to 42 per cent, reflects the intermittent nature of carriage of this micro-organism.

Analysis of data from one institution (Hospital 3) shows that six of the 54 people cultured more than five times each were consistently lacking in coagulase-positive staphylococci, a figure not out of line with other published data (Nahmias and Eickhoff, 1961; Williams, Blowers, Garrod, and Shooter, 1960). The same data show that 16 of the same 54 people consistently carried coagulase-positive staphylococci. The fact that the intermittent carriers (32 of the 54) frequently became recolonized by a different strain of coagulase-positive Staphylococcus than previously carried is interesting in that it may shed some light on how a persistent carrier or noncarrier differs from an intermittent carrier. There may be quantitative or qualitative variations in some factor that influences the carriage state. In the intermittent carrier, the varia-

tion of this factor may allow colonization by the strain prevalent at the time, which may or may not be the strain by which he was colonized in an earlier carriage state.

In one institution (Hospital 4), complete bacteriologic studies of nasal swabs of personnel allowed identification of all the bacteria present. From November 1, 1959, to January 31, 1962, 1,693 cultures were obtained; no nasal swabs were sterile. The most common bacteria were the staphylococci, present in 92.7 per cent of the cultures (coagulase-negative, 74.2%, and coagulase-positive, 18.5%). The Micrococcus and diphtheroid species were the next most frequently isolated (14.6 and 12.2%, respectively), which is not unusual. Nonhemolytic streptococci were next most common (4.5%), and Gaffkya species were recovered from 4.0 per cent of the plates, which is of interest in the light of its potential pathogenicity and yet its rarity in association with actual clinical disease. The recovery of *Escherichia coli* and even one shigella species underscores the variety of bacteria that potentially could be spread from the operating-room personnel to the patient (and vice versa).

Studies of Airborne Bacteria in the Operating Room

One measure of the effect of ultraviolet irradiation on airborne bacteria was obtained through the air sampling studies in the operating rooms. The use of shields (Hart grids) prevented the surfaces of the agar plates from being irradiated. The reduction in total numbers of bacteria recovered on the plates in irradiated, as opposed to unirradiated, rooms (from a 50.9% reduction during the initial, low-intensity phase, to a 63.0% reduction during the increased-intensity phase) indicates the effectiveness of ultraviolet irradiation in reducing the number of viable airborne bacteria. However, there was no similar variation in the wound infection rates between the low- and high-intensity phases, suggesting that airborne bacteria were not the most important factor in influencing the incidence of postoperative infection.

Studies of the operating-room sedimentation plates showed the coagulase-negative staphylococci to be the most prevalent organism in both the irradiated and the unirradiated rooms, accounting for approximately 50 per cent of all bacteria identified (Table 59). Coagulase-positive staphylococci and streptococci were identified on approximately 5 per cent of the plates, and other species on even fewer.

The sedimentation-plate results indicated great variations in the numbers of bacteria recovered in different operating rooms, even within the same hospital (Table 61). For example, in Hospital 1, the range is narrow, 5.47 to 5.90 colonies/plate (for shielded plates in irradiated rooms), but in Hospital 4, the range is 1.74 to 6.09 colonies/plate, and in Hospital 5, the range is 5.15 to 11.15 colonies/plate. If the operating rooms are ranked by mean colony counts, the order is generally similar, regardless of whether the irradiation or the control experience for a given room is considered. Thus, operating rooms appear to be associated with individual factors that significantly influence their degree of airborne bacteria.

Studies of Bacterial Contamination of Wounds at Time of Operation and Postoperatively

At one institution, special studies of the bacterial contamination of the wound at the time of operation and of the bacterial flora of postoperative drainage helped to clarify various relationships of wound, drainage, and environment. Wound cultures obtained at the time of operation showed the expected increase of bacterial contamination from clean, to clean-contaminated, to contaminated wounds (Table 63). That ultraviolet irradiation was effective in reducing the bacterial contamination of wounds is shown by the fact that 71.2 per cent of all irradiated wounds cultured were

sterile, as compared with only 60.2 per cent of all control wounds cultured (Table 64).

Comparison of infection rates, wound classifications, and bacteriologic data clearly shows the increased risk of infection in wounds contaminated by bacteria at the time of operation (Table 65). Thus, 5.4 per cent of all wounds shown to be contaminated at the time of operation developed frank infection, but only 1.0 per cent of the wounds sterile at the time of operation became infected. There is a similar difference for each wound classification between wounds sterile and contaminated at the time of operation. However, the increase in the prevalence of sterile wounds at operation associated with ultraviolet irradiation produced only a slight change in the infection rate, from 2.8 to 2.3 per cent.

Coagulase-negative staphylococci were the most prevalent bacteria isolated from wounds at the time of operation (which parallels the results of personnel and sedimentation-plate cultures), but other organisms were also recovered from the operative wound cultures. The prevalence of particular organisms was not greatly affected by wound classification, except for the increased frequency of the coagulase-positive staphylococci and *Escherichia* species in the contaminated and dirty wounds (Table 68–71). The same may be true for all the gram-negative organisms, although the data are too narrow to be of statistical significance. The low recovery rates of these organisms from the personnel and sedimentation-plate cultures suggest that the source of contamination may often be the patient himself.

Of the wounds that subsequently became clinically infected, 26.7 per cent (8 of 30) had initially produced sterile operative cultures (Table 67). This indicates either that the operative wound cultures are inadequate in revealing the presence of bacteria or that these wounds became colonized postoperatively. Of the 22 wounds that developed postoperative infections, and whose operative cultures revealed the presence of bacteria, 36.4 per cent (8) were contaminated by coagulase-positive staphylococci at the time of operation, 22.7 per cent (5) by coagulase-negative staphylococci, and 13.6 per cent (3) by nonhemolytic streptococci.

Ultraviolet irradiation appears to have no significant effect on the incidence of recovery of specific organisms at the time of operation, except possibly on coagulase-positive staphylococci, which were recovered approximately twice as frequently from unirradiated as from irradiated wounds (Table 76–80).

The wounds that developed infections most frequently were those which had been found at operation to be contaminated by coagulase-positive staphylococci. However, only 26.6 per cent of the infections yielded coagulase-positive staphylococci, and they were not always the same as the operative isolates. It remains to be seen whether or not a wound contaminated by coagulase-positive staphylococci is more susceptible to the development of postoperative infection. These data from one institution, although limited in significance, further indicate the lack of effect of ultraviolet irradiation on the development of postoperative wound infections. Continuation of these intensive studies is needed to define further the pattern of postoperative wound infection.

Studies of Bacterial Contamination of Wound Drainage

Cultures were obtained from all postoperative wounds that produced any drainage. Coagulase-negative staphylococci were isolated from 24.7 to 42.7 per cent, coagulase-positive staphylococci from 13.9 to 27.4 per cent, and the *Escherichia* species from 11.3 to 23.7 per cent of the drainages cultured (Table D-2). In the combined hospitals, coagulase-negative staphylococci were isolated from 32.4 per cent, coagulase-positive staphylococci from 19.3 per cent, and the *Escherichia* species from 15.1 per cent of the drainages. It is of interest that

enteric organisms accounted for 33.3 per cent of all recoveries from drainage cultures. Comparison with the low frequency of isolation of these species from the personnel cultures and sedimentation plates suggests an endogenous source of bacteria. The streptococcal species accounted for 14.2 per cent of organisms recovered from drainage cultures, which is of interest in the light of the low frequency of infections reported due to these species. Fifteen of the 33 isolates of beta-hemolytic streptococci were recovered at Hospital 2, which again indicates the presence of local factors, in this case, possibly a personnel carrier of beta-hemolytic streptococci. Comparison of the species recovered from sedimentation plates and from postoperative wounds revealed no important correlations, which represents further evidence of the absence of a close relationship between airborne bacteria and postoperative wound infection in these studies.

Dineen found (1961) coagulase-positive *Staphylococcus aureus* to be the single most common bacterium isolated from infected wounds among his 100 infected postoperative patients, being identified in 47. Of these, 36 were nontypable by routine bacteriophage methods. The enteric organisms were predominant in 49 cultures, with the enterococci or anaerobic streptococci being the most common (33 isolations). The *Escherichia coli* were the next most common (20 isolations).

Hnatko *et al.* reported (1963) the *Staphylococcus aureus* to cause from 51.8 to 83.1 per cent of the postoperative wound infections occurring from 1959 to 1961. Howe and Mozden reported (1963) that the *Staphylococcus aureus* was the most common pathogen found in their studies, followed by the enterococci, *Pseudomonas pyocyaneus, Escherichia coli, Proteus* species, and *Klebsiella aerogenes.*

Comparison of the postoperative wound cultures obtained from infected and uninfected wounds again reveals the prevalence of the staphylococci as the most frequently isolated organisms. However, whereas the coagulase-negative staphylococci were isolated with the same frequency in infected and uninfected postoperative wounds, the coagulase-positive staphylococci were isolated more than twice as frequently from the infected, 31.3 per cent, as from the uninfected postoperative wounds, 14.6 per cent (Table 86). The gram-negative enteric organisms were also recovered about twice as commonly from infected postoperative wounds. The variation from hospital to hospital points up again the importance of local variables in determining the organisms recoverable from wounds. This variability of bacteria recovered from postoperative wounds is also indicated in various reports in the literature (Chapter V, *passim*). The recoverability of potentially pathogenic organisms from uninfected wounds indicates the multiplicity of factors that influence the development of infection other than the mere presence of bacteria.

There was no significant difference between infected and uninfected wounds in the bacteria recovered postoperatively from irradiated wounds. But, as between irradiated and unirradiated wounds that did become infected, it is evident that ultraviolet irradiation did reduce the number of coagulase-positive staphylococci isolated from the infected wounds. It is equally interesting that coagulase-negative staphylococci and *Proteus* species were recovered more frequently from irradiated than from unirradiated postoperatively infected wounds (Table 89). The effect of irradiation may be to prepare a more suitable environment for growth of some bacteria postoperatively, such as the *Proteus* species; this effect was seen, however, in only three of the five institutions (Table D-5–D-9).

Coagulase-positive staphylococci were recovered uniformly from the postoperative drainages of all classes of wounds (Table 87). However, the recovery of coagulase-negative staphylococci steadily decreased

in the progression from clean through dirty wounds (35.9 to 16.3%) and the nonhemolytic streptococci increased (8.3 to 14.3%). The other organisms do not show consistent changes. These data further indicate the endogenous source of wound contamination.

Phage typing of the coagulase-positive staphylococci isolated from wounds at the time of operation and from the postoperative wound drainages revealed no significant patterns. The data concerning the recovery of staphylococci from wounds at the time of operation are limited to one hospital (Hospital 4). Of the 31 isolates, 19 were nontypable. Two each were typed by the 52/52A/80/81 and 80/81 phages. Of the 146 wounds that were cultured both at the time of operation and postoperatively, 14 became infected. None of the 14 infections yielded the organism that had been recovered during operation. A total of 334 coagulase-positive staphylococci were recovered from the postoperative wound drainages, and 185 (55.4%) were nontypable. Sixty different phage patterns were reported, with the greater number falling within phage Group III. The 80/81 phage type was common to 26 (7.8%) of the organisms tested. It is well known that there is great variation in the phage-typing patterns of organisms isolated from different institutions (Markham and Shott, 1961); considering the fact that there were no epidemics of staphylococcal disease in these institutions during the period of study, the results are not surprising. The number of nontypable strains is not out of proportion to other reports, and, although phage typing with 1,000 RTD phage was not done, there was no suggestion that it would have revealed any predominant strain.

Minchew and Cluff reported (1961) that phage type 80/81 was responsible for 30.3 per cent of their postoperative staphylococcal infections; 28.3 per cent were nontypable. The Public Health Laboratory Service in England reported (1960) that 46.9 per cent of the staphylococci isolated from septic wounds were of Group I, 29.7 per cent were of Group III, and 17.3 per cent were nontypable.

Discussion

Micro-organisms can be spread either directly or indirectly. The direct routes include spread from either a carrier or a person with active disease by means of direct contact with the recipient, with organisms being transferred from the hands, perineum, or other areas of carriage, or directly from the lesion itself. Organisms can also be spread directly through the air by droplets which come into direct contact with the recipient.

The indirect route of transmission involves travel from either the carrier or the person with an active lesion through an intermediary such as the air, in the form of droplet nuclei or fomites (e.g., dust, bedding, or utensils), which come into contact with the recipient. Another indirect route would be from one person to another through the actions of a carrier such as a nurse. In each of these cases, the recipient may either develop clinical disease or become a carrier of the organism himself.

Culbertson *et al.* have summarized (1961) the literature on the epidemiology of postoperative infection of clean wounds. They reported, on the basis of their own studies, that "contamination by direct contact is responsible for the majority of these infections." Howe and Mozden, summarizing their studies (1963), felt that "the majority of serious infections that could be documented in clean closed wounds were seeded in the operating room during surgery," and they could document an association between the infecting staphylococcus and a carrier in the operating room in half their cases.

Other reports (e.g., Hart, 1938a; Blowers *et al.*, 1955; Hare and Ridley, 1958; Hudson *et al.*, 1959; Adams and Fahlman,

1960) stress the airborne route as the most important in transmitting pathogenic bacteria. Bernard and Cole, however, did not believe (1962) that, during their 24-month study of the air in two operating rooms, air contamination had any influence on the postoperative infection rate. They stressed that the reduction in postoperative infection rates would follow improvement in the technics of aseptic surgery, rather than efforts to reduce the airborne bacteria. Colbeck, in discussing (1960) staphylococcal infection, stated that "the number of staphylococci likely to gain entrance into a wound from the atmosphere is very small and not likely to be important." He believed that hands and other objects were more important in contaminating wounds.

The importance of the patient carrier as concerns staphylococcal infection has been stressed by Williams (1958; Williams, Blowers, Garrod, and Shooter, 1960; Williams *et al.*, 1959) and Weinstein (1959b). Their reports indicate that the patient carrier is a main source of infection. Accordingly, preoperative therapy with antibiotic nasal ointment has been reported to reduce the incidence of postoperative wound infection; other investigators (Public Health Laboratory Service, 1960; Bassett *et al.*, 1963), however, have not confirmed these results.

The data from the present study do not indicate clearly which route was of major importance in the development of postoperative wound infection. There is some evidence to indicate the importance of the patient in infecting his own wound. There is no convincing evidence that droplets or persons with active lesions had any role, and the limited studies of operating-room personnel do not indicate that the presence of carriers was related to disease.

Considering indirect routes of transmission, there is no evidence of the role of a carrier or of droplet nuclei. Fomites were not adequately studied to determine their role. Indirect transmission through a carrier may have been a factor of spread, but the data obtained did not allow further evaluation. It must be remembered that all these studies cover a nonepidemic period.

There is ample evidence that the development of postoperative wound infections was not primarily related to the operating-room airborne bacteria: 1) the overall postoperative wound infection rate was not reduced by the use of ultraviolet irradiation, whereas the airborne bacteria were reduced by 56.3 per cent; 2) although the settling airborne bacteria were reduced by 12 per cent from the low- to the high-intensity irradiation period, there was no similar change in the infection rates; 3) the longer operations, with their associated longer opportunities for airborne bacterial contamination of wounds, showed no significant difference in infection rates between the irradiated and the unirradiated rooms; and 4) there was little correlation among the bacteria isolated from the air, from the wounds during operation, and from the postoperative infections.

Not all the factors that influence the development of postoperative wound infections have been defined, but the data do indicate that in the five participating hospitals an increased incidence of postoperative infection is related to age, obesity, steroid treatment, existing infection separate from the operative site, the use of drains, the length of the operation, possibly the prophylactic use of antibiotics, and the operative or preoperative contamination of the wound as defined by wound classification. Nevertheless, one of the most striking findings has been the great difference in infection rates (for given operative procedures) between one participating hospital and another. This would appear to place a major responsibility upon the operating team for the prevention or development of many postoperative wound infections.